



Understanding farmers' decisions on adaptation to climate change: Exploring adoption of water harvesting technologies in Burkina Faso

Lisa Bunclark^{a,*}, John Gowing^a, Elizabeth Oughton^a, Korodjouma Ouattara^b, Sidonie Ouoba^b, Diane Benao^b

^a School of Agriculture, Food & Rural Development, Newcastle University, Newcastle upon Tyne, NE1 7RU, UK

^b Institut de l'Environnement et de Recherches Agricoles (INERA), BP 10 Koudougou, Burkina Faso

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ABSTRACT

Continued efforts are required to reduce the risk and vulnerability of small-scale farmers in the drylands of sub-Saharan Africa in the face of increasing rainfall variability and long term climate trends. The adoption of water harvesting (WH) is examined as one possible strategy to better conserve agricultural resources and increase production. A case study approach based in Burkina Faso is used to explore farmers' attitudes to innovation via a qualitative methodology. Farmers' experiences of WH adoption and use over time are considered in relation to the 'bright spots' discourse to enable the identification of further lessons about adoption drivers for innovations aimed at reducing risk and vulnerability in small-scale agriculture. By rethinking the conceptualisation and definition of WH adoption, as well as considering use of the techniques over time rather than at the point of initial adoption alone, this research provides evidence of the dynamic nature of WH adoption and use by farmers. It demonstrates that adoption is not a dichotomous decision and that levels of intensification, modification, abandonment and replacement by farmers vary over time. Use of the sustainable rural livelihood framework highlights how this can be linked to the dynamic nature of the systems within which farmers derive their livelihoods and the need to continually adapt to dynamic, irregular and uncertain conditions (vulnerability context). These lessons from WH experience in Burkina Faso have wider implications for the promotion of climate adaptation innovations for small-scale farmers in SSA.

1. Introduction

1.1. Adapting to a changing climate in Sub-Saharan Africa

The IPCC 5th Assessment Report (Niang et al., 2014) points to an increased warming trend across Sub-Saharan Africa (SSA) over the last 50 to 100 years and concludes that it is likely that land temperatures will continue to rise faster than the global land average. African ecosystems are already being affected by climate change, and future impacts are expected to exacerbate vulnerability of agricultural systems, particularly in semi-arid areas. Such macro level changes in-turn influence the complex combination of context-specific environmental and socio-economic factors that have been found to shape risk and vulnerability in farming systems at the local level, including resource availability, resource use intensity, governance, markets and consumption patterns (Sietz et al., 2017). In the recent past, progress has been made in efforts to manage risks to food production from climate variability and the related increase in soil erosion, but continued efforts are

required to improve the resilience of agricultural systems. An array of resource-conserving agricultural practices is identified as offering climate adaptation options (Lipper et al., 2014). We focus on one such climate adaptation option – the adoption of water harvesting (WH) by small-scale farmers in order to alleviate drought vulnerability in semi-arid cropping systems.

There are some good news stories; 'bright spots' of successful adoption of 'resource-conserving' techniques by individuals and communities across SSA have been identified (Pretty et al., 2006; Noble et al., 2008; Bossio et al., 2008). These represent cases where land degradation has been reversed or mitigated and household food security and livelihoods have been improved through agricultural innovation. They involve better use of natural resources to increase total farm production, such as through adoption of WH. In the majority of cases, the development of a 'bright spot' has been seen to be contingent on an external priming agent (such as an NGO or government project). Where a 'bright spot' is said to exist, there is evidence that improvements have been sustained beyond the lifetime of this intervention.

* Corresponding author.

E-mail address: lisa.a.bunclark@gmail.com (L. Bunclark).

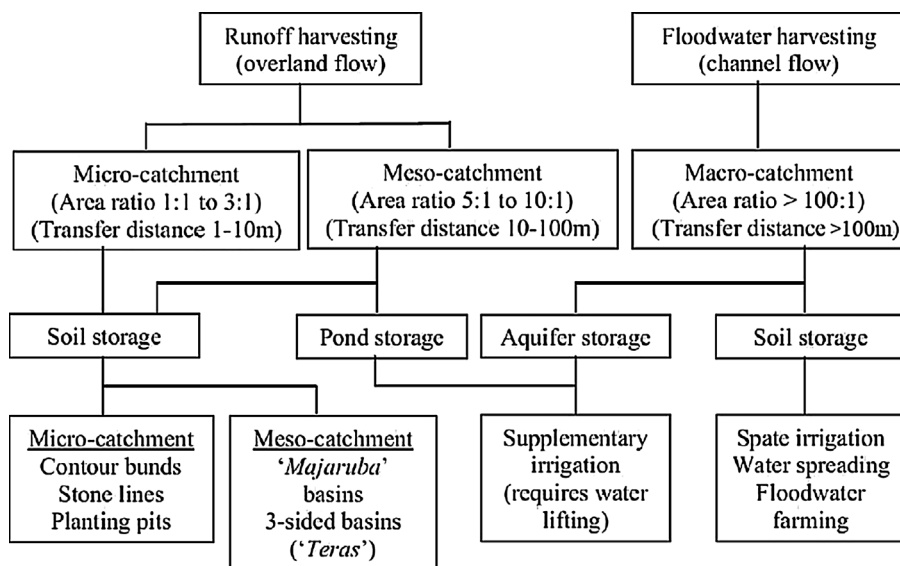


Fig. 1. Classification of water harvesting practices.
(Source: Gowing and Bunclark, 2013).

However, evidence for 'spontaneous' adoption outside the project site is generally lacking. We consider how the experience of WH innovation compares to the 'bright spots' discourse and identify some lessons about drivers of adoption of this innovation for reducing vulnerability to both existing climate variability and future climatic changes.

Previous studies have largely viewed WH innovation as a dichotomous decision (adopt Yes/No) as determined by characteristics of adopters and non-adopters at a certain point in time. However, recent research has shown the adoption of WH techniques to be a highly dynamic process, where levels of adoption, modification, abandonment and replacement vary over time (Mazzucato and Niemijer, 2000; Sietz and van Dijk, 2015). Nevertheless, over-simplified conceptualisations of WH adoption still persist. This reflects the 'deeply flawed' concept of technology adoption that underpins much of the research agenda on agricultural technologies in developing countries (Glover et al., 2016).

This paper focuses on the adoption and use of WH in Burkina Faso, as it represents a good example of small-scale farming and WH use in SSA. Since the 1980s, governmental and non-governmental organisations (NGOs) have continued to actively promote the use of a range of WH across Burkina Faso in a bid to help small-scale farmers, who account for up to 90% of the working population (FAO, 2014). This innovation aims to reduce soil degradation and the risk of crop losses linked to unpredictable and highly variable climate, which were considered the primary constraints to crop production (Sawadogo, 2011; Douchamps et al., 2012; Critchley and Gowing, 2013). We report an investigation based on extended fieldwork during 2013 and 2014 which attempted to identify drivers of WH adoption while recognising it as a dynamic process. In response to Sietz and van Dijk (2015), we provide insight into the motivation, rate and time of intensification, modification, abandonment and replacement.

1.2. Introduction to water harvesting techniques

In the semi-arid and dry sub-humid zones of SSA, it is not the limited amount of rainfall alone that constrains rainfed crop production. Rather, it is the extreme variability of rainfall, with high rainfall intensities, few rain events, and poor spatial and temporal distribution (Molden et al., 2007). Dry spells occur in almost every rainy season and adapting to these, and future changes to climate, depends on developing appropriate techniques to bridge these dry spells, reduce the risk of crop loss and increase productivity (Lipper et al., 2014). Water harvesting – a broad term often used interchangeably with 'rainwater harvesting' – is an innovation which aims to alleviate this constraint and is widely considered the key to unlocking full potential of rainfed

agriculture (Rockström et al., 2007). We adopt the definition proposed by Critchley and Scheierling (2012): "The collection and concentration of rainfall runoff, or floodwaters, for plant production". They present a classification of water harvesting systems adapted from that developed by Critchley and Siegert (1991). Other classifications proposed by Fox (in Falkenmark et al., 2001) and Oweis and Hachum (2006) are similar.

In these various classifications a distinction is often made between techniques on the basis of where the runoff is collected and how far it is diverted. Runoff may be collected from fields, hill-slopes, house roofs, roads and tracks, or ephemeral streams and gullies. Rainfall may be captured locally on the farm where it is to be used, or as runoff from rain that falls beyond the farm boundary. The classification adopted here (see Fig. 1) divides water harvesting into floodwater harvesting (channel flow) and rainwater harvesting (overland flow). Water harvesting practices may also be distinguished on the basis of how the captured water is stored. Some rely on storage within the soil reservoir of the cropped field, while others incorporate storage in ponds and cisterns. In the latter case the stored water can then be used for supplemental irrigation on the adjacent cropped field at a time of the farmers' choosing.

Over the last 20 years the literature on water harvesting in SSA has proliferated. Vohland and Barry (2009) limit their discussion to 'in-field water harvesting practices' in African drylands and list 98 references published in the last 20 years. Biazin et al. (2012) deal with 'rainwater harvesting and management' practices in Africa and therefore cover a wider range of options. They list a total of 160 references, 90% of which were published in the last 20 years. Bouma et al. (2012) adopted a broad definition and identified 300 studies from SSA. Evidence from experimental plots and from farmers' fields appears to show that a range of SWC practices can deliver increased productivity (Bayala et al., 2012), but this has not resulted in diffusion of the innovation to the many farmers who could derive benefit from its adoption (AfDB, 2007; Molden et al., 2007).

This paper focuses on the micro-catchment WH techniques that have been promoted in Burkina Faso, in particular:

- Planting pits (known locally as *zai*); typically 20–30 cm diameter, 10–25 cm depth and spaced about 80–100 cm apart;
- Stone lines (known as locally *cordons pierreux*) and earth bunds (known locally as *diguettes en terre*) as contour barriers; typically 25 cm height with base width of 35–40 cm and spaced at 15–30 m apart.

Descriptions of these techniques are readily available in the

literature (see for example Critchley and Gowing, 2012; Lasage and Verburg, 2015) and in the WOCAT knowledge base (www.wocat.net).

1.3. Defining adoption

There is an extensive literature in which researchers have explored the process of agricultural technology adoption (Feder et al., 1985; Doss 2006; Loevinsohn et al., 2013). A substantial part of this literature has focused on adoption by smallholder farmers in developing countries. Such studies may provide insight into (i) the success of interventions which aimed to promote adoption of a particular innovation and/or (ii) the factors which influence adoption by particular smallholder farmers. This requires consideration of how we distinguish between adopters and non-adopters and this in turn requires clarity on the definition of an adopter. The issue was identified by Feder et al. (1985) but it persists and in the recent systematic review by Loevinsohn et al. (2013) only 12 of the 214 selected sources provided a functional definition of adoption.

The literature on innovation in small-scale agriculture can be categorised according to ‘traditions of research’ (Loevinsohn et al., 2013), which reflect different paradigms of technology change. In their systematic review Loevinsohn et al. (2013) recognised these as:

- Economic tradition which focuses on cost/price information as the driver;
- Diffusion tradition which focuses on personal characteristics and endowments that condition response to information about technology;
- Local innovation tradition which focuses on active involvement and agency of farmers rather than viewing them as passive adopters.

Alternatively the literature on technology adoption can be categorised according to methods used to investigate change. In a comprehensive, but not systematic, review Doss (2006) recognised:

- Econometric modelling methodologies;
- Examinations of the learning and social networks involved in technology adoption;
- Micro-level studies based on local data collection rather than broader census data.

All of these categories generally rely on cross-sectional data and adoption is studied from a static and dichotomous viewpoint because cross-sectional data do not permit analysis of the dynamics of technology adoption. However, recent research on the adoption of agricultural technologies in developing countries (Glover et al., 2016), as well as soil-and water conservation (SWC) technologies, such as WH more specifically (Sietz and van Dijk, 2015), has again shown that such

conceptualisations pose a major constraint to increasing understanding of farmers’ adoption and use of agricultural technologies. Glover et al. (2016) note that most adoption studies are inappropriately underpinned by:

‘...a “black box” conception of technology as discrete, generic, transferable packages of material and practical components, and... a conception of technological change as constituting a... dichotomous yes/no, once-and-for-all and linear progression.’

An alternative framing of technology adoption is therefore required to advance understanding and increase the validity of conclusions stemming from related studies, both generally (Glover et al., 2016) and for WH in particular (Sietz and van Dijk, 2015). In accordance with the concept of local innovation and consideration of adoption as a complex and dynamic (as opposed to static and dichotomous) process, this paper follows guidelines on the analysis of technology adoption set out by Doss (2006). These guidelines suggest three different variables that any study into technology adoption should examine:

1. Conceptualisation of adoption: A discrete state with binary variables (adopt or not), or a continuous measure (degrees of adoption)?
2. Definition of the technology: The extent to which it is used ‘correctly’, or effectively, or are there other ways in which farmer behave that can be identified?
3. History of use: Are farmers currently using the technology, or have farmers used it in the past and later dis-adopted, or not used the technology at all? (Doss, 2006).

2. Approach and methods

2.1. Theoretical approach

Farmers’ decisions about whether to adopt a new technology depend upon (i) characteristics of the technology itself and (ii) the context within which they operate. We adopt the sustainable rural livelihoods framework (Scoones, 1998, 2009) as the approach to understanding the context. This framework (SRLF) defines livelihoods in relation to five key indicators: resources, strategies, contextual environment (including policy, climate, demography), institutional and organisational structures and processes, and outcomes (Clark and Carney, 2008; Prowse, 2010). It provides the ideal basis for the exploration of factors that influence the adoption, intensification, modification, abandonment and replacement of WH techniques as it provides a holistic and integrated assessment of the system within which households are able to achieve sustainable livelihoods and the part (if any) WH plays in this process.

The SRLF used in this research is an expanded version of Ashley and Carney’s (1999) framework, as shown in Fig. 2, which incorporates recent developments in understanding of the nature of rural livelihoods

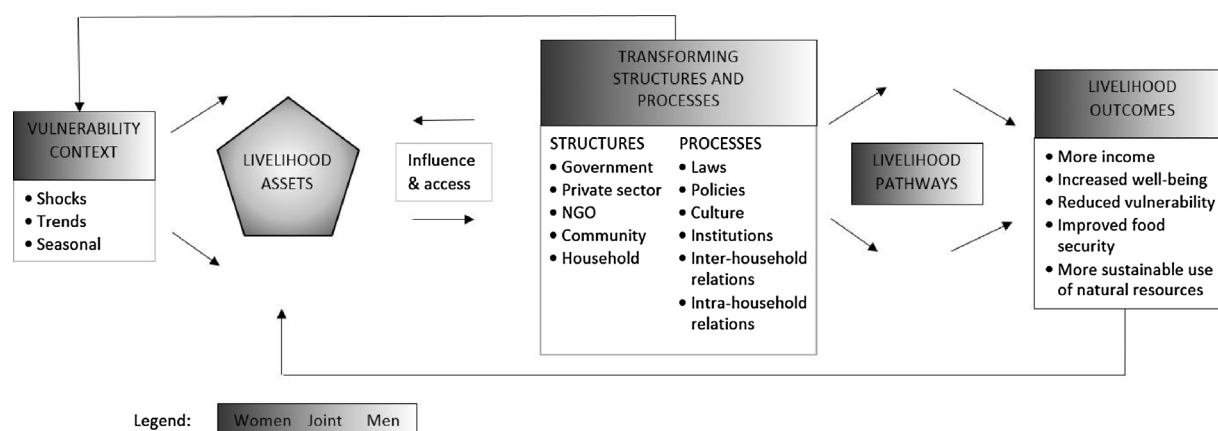


Fig. 2. Expanded livelihood conceptual approach used, based on the Sustainable Rural Livelihoods Framework. (Adapted from: Ashley and Carney, 1999; Meinzen-Dick et al., 2011)

with respect to transforming structures and processes (TSPs), and livelihood strategies. The TSP box has been expanded to allow for consideration of the major influence that institutions have on livelihood opportunities and constraints for different types of people (depending on age, wealth and gender for example) at different stages of the framework. In particular, this allowed for deeper investigation of the influence of power relations within the household on access to and control of assets and the influence this had on WH adoption and use over time.

2.2. Methodology

An overview of the research methodology is provided in the following section, a more detailed explanation can be found in Bunclark (2015). A location-based, micro-level (case study) methodology was adopted due to its inductive approach and ability it provides to observe and explore WH practices in detail within the real-life context of small-scale farms (Yin, 2009). Burkina Faso was selected as the case study country as it represents a good example of small-scale farming and WH use in SSA. As is the case across SSA, rainfed farming in Burkina Faso is conducted in the context of highly variable rainfall and WH has been promoted and implemented widely by both governmental and non-governmental organisations since the 1960s, with the aim of improving food security and livelihoods of rural households (Kabore-Sawadogo et al., 2013).

A total of three case study villages were selected for this research: two sites (Boukou and Malgretenga) located in the centre of the country and one (Peni) located in the south-west, as shown in Fig. 3. Boukou and Malgretenga represent typical villages in the Central Plateau region of Burkina Faso, where annual rainfall is around 800 mm, soils are poor quality, small-scale farming makes the primary contribution to livelihoods, there is a long history of WH promotion and implementation, and institutions are a mixture of modern and traditional systems. Peni represents a typical village in the south-west of the country, where soil quality, livelihoods and institutional structures are broadly similar to those in Boukou/Malgretenga, but rainfall levels are higher (around 1000 mm) and WH promotion and implementation is more recent and less widespread compared to the centre and north of the country. (A more in-depth explanation of environmental and socio-economic characteristics of the country as a whole and each case study site can be found in Bunclark (2015)). The case study sites were identified and

selected in collaboration with the local partner organisation, Institut de l'Environnement et Recherches Agricoles (INERA) in order to provide a range of experience of WH adoption and use.

The first case study site, Boukou is located approximately 60 km northwest of the country's capital city, Ouagadougou. Boukou is located within the Sudan-Sahel climatic zone with average annual rainfall of 730 mm (occurring primarily between June and September). The farming system is predominantly based on cereals production (sorghum and millet). Leached ferruginous soils cover the greatest area (BUNASOL, 2002). These soils have a variable texture, generally tending to be sandy in their surface horizons and clayey below 40 cm. They all have a poor cation exchange capacity and are associated with degraded gravelly soils (Fontès and Guinko, 1995).

Discussions with research participants in Boukou suggest that WH practices were first introduced into the village via government-led programmes in the mid-1980s. During this period, agricultural extension officers worked together with the farmers to construct earth and vegetated bunds. The use of these techniques has reduced over the years with the promotion and construction of stone lines by both government and non-governmental-led projects in the 1990s and 2000s. One of the main external organisations assisting farmers with the installation of WH is the Organisation de Developpement Evangelique (ODE) or Evangelical Development Organisation. Planting pits (locally known as *zai*) are used by a small number of farmers, primarily those who have received training in the practice via INERA in the 2000s.

The second case study site, Malgretenga, is located in the commune of Nagreongo, Ouhritenga province, Central Plateau region. Malgretenga lies approximately 40 kilometres east of Ouagadougou and was created by the Autorité pour l'Amenagement des Vallées des Volta (AVV). The AVV was a state body created in the early 1970s in order to lead the colonisation of areas within the Volta valleys, as a strategy to help farmers cope with the low and highly variable rainfall occurring in that period (Zoungrana, 1995). Malgretenga is also located within the Sudan-Sahel climatic zone with average annual rainfall of 750 mm and like Boukou with a wet season occurring primarily between June and September and long hot dry season from October to April. The farming system is predominantly based on cereals production (sorghum and millet). Soils are similar to those at Boukou (BUNASOL, 2013a).

Of the three sites, Malgretenga has the longest history of WH promotion and use. Projects related to stone lines have been implemented in the village since its creation in 1974. Many other governmental and



Fig. 3. Map showing location of research study sites in Burkina Faso.
(Map Source: CIA, 2011)

non-governmental programmes and projects have promoted and assisted the construction of WH in the village throughout the last four decades (GoBF, *ca.*, 2007a). Vegetated bunds are also used in the village, although to a much lesser extent than previously as they have gradually been replaced by stone lines. Zaï are used by a small number of farmers, although there are also a number of farmers that have used zaï in the past and since discontinued their use.

Peni is located in south western Burkina Faso approximately 30 kilometres from the country's second largest town, Bobo-Dioulasso, and is bisected by national route N7, which links Burkina Faso to the Ivory Coast. As a result of continued immigration, particularly of Mossi and Pehls from the north, the population of both the village and commune of Peni has increased rapidly since the 1980s (GoBF, *ca.*, 2007b). Peni lies within the Sudanian climatic zone with average annual rainfall of 1000 mm, most of which falls between May and September (GoBF, *ca.*, 2007b). The farming system is based on cereals (maize), tree crops and cotton production. Ferralitic soils are found in this area (BUNASOL, 2013b). They are good agricultural soils with wooded savannah as the natural vegetation (Fontès and Guinko, 1995).

Unlike the other two study sites, the use of WH in Peni for collection of runoff in-field appears to have begun relatively recently, since the early-2000s. Qualitative data collected from research participants in the village indicate that during the last decade, there have been a small number of projects implemented by external governmental and non-governmental organisations that have promoted the adoption and use of WH for collection of runoff in-field. A very small number of farmers use planting pits, particularly those that have migrated from northern areas of Burkina Faso, although knowledge of them is by no means widespread. Prior to the promotion of WH, earth bunds and vegetation were traditionally used only for the diversion of runoff away from fields to alleviate flooding and crop damage, rather than alleviate droughts.

2.3. Data collection and analysis

At each case study site, existing secondary data were used to establish the socio-economic, cultural and institutional context of rural agricultural livelihoods. Primary data was collected during two extended periods of fieldwork in 2012 and 2013. Fieldwork in both years was conducted during the dry season between February and June, as farmers have fewer demands on their time during this period and the data collection process was considered to have less negative impact on their livelihoods. Qualitative data was collected and recorded by a team comprising a UK-based researcher, a research assistant employed by INERA and an interpreter employed at a local level. Some key informant interviews were conducted in French without the use of the interpreter; these were primarily those with regional/national level key informants.

Several participatory techniques were used with men and women from selected households to explore the factors that have influenced and continue to influence the adoption and expansion of WH techniques, as well as how these factors have changed over time. In 2012 and 2013, two focus groups with 10–12 participants were carried out at each site separately with men and women from the village to explore the characteristics of agricultural production, institutional context, knowledge of WH and perceived nature of costs and benefits from WH. In 2013, a transect walk with 5–7 participants was also conducted in each village to gather information relating to land use and management (including WH).

In addition to participatory activities, a sample of 38 households (between 11 and 14 households in each site) took part in semi-structured interviews, which were held with the head of household and their spouse (where present). Interviews were conducted with the same individuals at each site in 2012 and 2013. Overall, a total of 111 interviews were conducted (plus 22 surveys in Peni in 2012, when interviews were not possible due to onset of rainy season). Key informants were also sought to provide information on key themes identified

during the process of data collection and analysis. In total, 38 interviews were held with key informants; 6–7 local-level key informants were interviewed at each case study site, along with 12 regional/national level key informants based in Ouagadougou.

For most data collection activities, a snowball sampling strategy was used to identify research participants. Snowball sampling is a form of purposive sampling that allows for participants who are most relevant and able to provide insight into the research questions to be identified and selected (Bryman, 2008). For the household level interviews and survey, participants were purposefully selected via key informants and other participants. Households were selected across four main categories, with the aim of at least three farmers in each of the four categories. These were:

1. Farmers currently using WH techniques in all or part of their family fields who had adopted with the assistance of an external intervention or work group;
2. Farmers currently using WH techniques in all or part of their family fields who had adopted without the assistance of an external intervention or work group;
3. Farmers not currently using WH techniques in their family fields, but who had done so in the past;
4. Farmers not currently using WH techniques in their family fields and who had never done so in the past.

In these categories, 'using WH' and 'not using WH' were user-defined and relied on farmers classifying themselves as users or non-users. The final number of households falling within categories three and four was less than required in Boukou and Malgretenga due to the long history of WH interventions in these sites. Aside from the four broad categories listed above, households were also selected to provide a range of farming households and individuals with different characteristics, with different ages and gender of household head, sizes of household and relative level of wealth. Within male-headed households, those with a range of WH use by women in the fields they cultivated and managed separately from the family fields were also sought. Due to the time constraints, it was not feasible to use a snowball sampling method to identify focus group and transect walk participants. In this case, gate keepers (with assistance of key village representatives, where necessary) selected participants according to who they considered fitted the sampling criteria stipulated by the research team. The sampling criteria for focus groups were the same as for the household level interviews, as outlined above. For the transect walk, participants were selected for their in-depth knowledge of village land use and management issues both past and present.

Data collection and analysis were conducted as an iterative process, both within and between each phase of fieldwork. Broad themes explored in data collection included: basic household information, level of asset endowment, livelihood activities engaged in (productive and non-productive), markets, agricultural knowledge and use of WHTs, food consumption and credit. During data collection phases, analysis comprised discussion of observations and notes taken by the field team as soon as possible after the research activity. This process allowed for emerging themes to be identified and investigated over the course of each data collection phase. After each such phase was completed, in-depth analysis began with transcription of fieldwork records. Data related to similar themes was grouped together and assigned a category name (or code). In each analysis phase, within-case analysis was first conducted to identify specific patterns and develop familiarity with each individual case study site. This was followed by cross-case analysis in which data from each case study site was compared and contrasted. In order to explore relationships between different factors, charts and diagrams were produced, matrices were used to document the profile of participants, and typologies were formulated. For example, data regarding level of asset endowment, livelihood activities engaged in and the function these activities played in household livelihoods were

compared using matrices, which enabled households to be grouped into different livelihood pathway types. A follow-up visit to the case study sites was conducted in February 2014 to gain feedback from the community on initial findings.

3. Results and discussion

3.1. Towards an alternative framing of WH adoption, from innovators to the unaware

It was not possible to classify farmers into two distinct groups of adopters or non-adopters, as generally conducted in previous studies on the adoption of WH. Rather, adoption occurred along a spectrum. For example, the extent and intensity of WH application varied greatly between households. Within those households who reported they were using WH, adoption varied from application across all fields, to use only in a proportion of fields.

The extent to which WH practices were used in line with ‘best practice’ as recommended by researchers and development practitioners, also varied greatly. Some farmers adopted the technologies as recommended, whereas others used components or principles of the technologies only. There were two main types of farmers within this category. Firstly, those who had installed stone lines, earth bunds or vegetated bunds that follow a straight line to intersect the general direction of runoff, but do not follow contours. Secondly, those who had installed only short sections of stone lines and/or vegetated bunds in areas of greatest runoff only, rather than in continuous lines across the full width of fields.

These data provide further evidence that the current widely used conceptualisation of WH adoption (and agricultural technologies more broadly) – as a dichotomous variable where adoption represents use of the technology in conformity to their widely accepted definition at a certain point in time – is not appropriate. For this study, therefore, adoption was considered to encompass use of any aspect of WH, conforming in full or part to their widely accepted definitions. History of use was also taken into consideration so that ‘dis-adopters’, defined as those who were not currently using WH but had done so in the past, were identified as distinct from ‘non-adopters’.

Based on this new conceptualisation of WH adoption, a typology

Table 1
Typology of water harvesting adoption and use.


Increasing extent of adoption	WH category	Core characteristics
	Innovators	Combining technologies, particularly stone lines and zaï. Experiment with new technologies not traditionally used in their village/region with little external support. Have the capacity to expand use of WH without external support.
	Investors	Extensively adopt WH and are expanding use after successful initial application, mostly zaï but not necessarily. Expansion of WH and/or use of zaï mainly driven by desire to gain additional income/improve the land for the future as an investment (legacy).
	Augmenters	Substantial proportion of their fields treated with stone lines and earth bunds. WH adopted and expanded through numerous projects or with a mixture of self-adoption and projects. In most cases farmers use projects to install stone lines in areas with most damaging runoff and then augment this with earth bunds installed themselves or with projects. These farmers may also use small areas of zaï on the most degraded areas of land.
	Savvy adopters	Adopt principles of WH to reduce runoff only in areas where it damages crops.
	Passive adopters	Adopt stone lines with a project, or use the technology their father did (e.g. zaï) but have not expanded area of application. Women in this category adopt stone lines using leftover materials from projects in family fields. In most cases WHTs are just used where needed (i.e. where runoff is damaging to crops, or in the case of zaï, where land is severely degraded). Extent of adoption is relatively low compared to Augmenters.
	Receivers	Cultivating with WH only in gifted or rented fields which already had the technologies in place.
	Leavers	Adopted and used WH in the past but no longer maintain them, or have not re-adopted where moved to cultivate new fields (i.e. those that have dis-adopted). Generally WH has not been re-adopted as farmers do not have the assets to install them and/or no longer see a need to.
	Non-users	Knowledge of WH and how to construct them, but has never adopted (in fields they manage) as do not have the tools, materials and other assets required to install them, or do not consider it necessary to put them in any of their fields. (Women within MHHs in this category may work with WH in family fields, but not in their own fields.)
	Unaware	No knowledge of WH techniques or how to construct them

Table 2

Male heads of household, female heads of household and women within male-headed households within each WH category.

WH category	WH category members	
	Male and female heads-of-household	Women in male-headed households
Innovators	3	0
Investors	5	0
Augmenters	7 (1) ^a	0
Savvy adopters	1	2
Passive adopters	7 (2)	3
Receivers	0	5
Leavers	3 (1)	2
Non-users	2	11
Unaware	3 (2)	0
Unknown why no WHT	0	4
Total	31 ^b	27 ^c

Notes:

^a Number in brackets signifies number of female-headed households within this total.

^b Seven households studied were only using WH in test plots of 0.25 ha as part of INERA experiments and were not included in the typology developed.

^c Four women in male-headed households cultivate in family fields only, or not at all and hence are not included in the table.

outlining the differences in nature of WH adoption and use between farmers was developed. As presented in Table 1, nine different categories can be identified in relation to levels of knowledge, extent/intensity of WH use, and the way in which WH was adopted (and in some cases expanded). These range from those with no knowledge of WH (*Unaware*), to those that have adopted WH on a large-scale and experimented with new technologies (*Innovators*).

Some farmers used WH only as they were gifted a field with WH already installed (*Receivers*). Some only used principles of WH rather than contour stone lines or earth bunds across the full width of their fields (*Savvy adopters*). Those heads of household in the *Leavers*, *Non-Users* and *Unaware* categories were generally relatively poor households, particularly female-headed households. As shown in Table 2, the most common categories that male heads-of-household fell into were the *Augmenters* and *Passive adopters*. Most women within male-headed

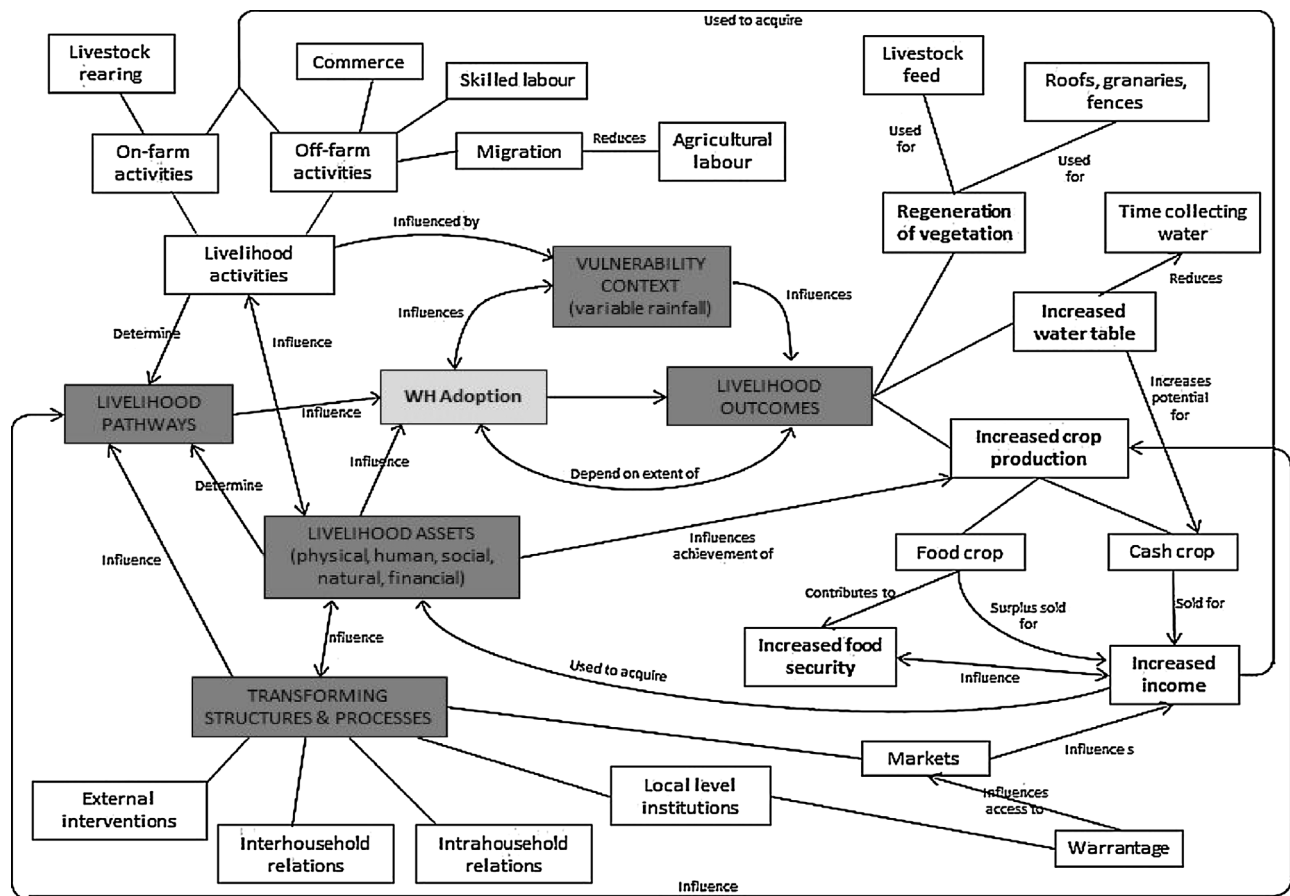


Fig. 4. Concept diagram of the main links and interactions between factors that affect the adoption and use of WHTs observed and identified in the process of this research.

households were in the *Non-users* category and had not adopted the technologies in their fields despite having knowledge of them.

Longitudinal data collected regarding changes to WH adoption and use in households highlights that farmers may move between categories over time as decisions are made to adopt, expand, modify, dis-adopt or re-adopt in response to changing circumstances at household level, which may be short-term (temporary) or longer-term (permanent) changes. Reactions to these changes can also be rapid with immediate, change in WH investment (due to the death of household member or change of land cultivated, for example) or gradual with slowly increasing or declining investment in WH over the period of a few years (in line with an increasing or decreasing asset base, for example), as explained in more detail in the following sections of the paper.

3.2. Understanding decision-making on WH adoption (and abandonment)

Through the use of the SRLF in this research, it has been possible to identify and explore the main links between the multiple factors affecting the decisions farmers make on whether to adopt, expand and/or abandon their use of WH, as presented in the concept diagram in Fig. 4. Previous research has recognised that this dynamic and complex adoption process is linked to the vulnerability context under which farmers operate, shaped by shocks such as drought, and longer term trends linked to growing uncertainty and variability in rainfall, changes in land use and changes in government policy (Toulmin and Chambers 1990; Boyd and Turton, 2000; Kabore and Reij, 2004; Ngigi et al., 2007), but little is known about the wider context that influences farmers' decisions on adoption, expansion or dis-adoption of WH (Sietz and van Dijk, 2015). The following discussion seeks to demonstrate how the SRLF can facilitate improved understanding of this decision-making process.

3.2.1. Livelihood pathways and the role of WHs in livelihoods

Livelihood pathways can be thought of as what households are doing to make a living (Levine, 2014), or more specifically, the activities household members are engaged in and the contribution they make towards livelihoods (Dorward et al., 2009). Although all households in the case study sites can be considered as small-scale farming households, the use of a livelihoods approach helps to highlight differences in how they make a living (activities engaged in and the function these activities play), how this may change over time and the importance of WH in each case. Use of the SRLF allowed for investigation into the influence of vulnerability context, assets and TSPs in shaping these livelihood pathways and hence WH use.

Agriculture is a key livelihood activity in the case study sites, with other productive activities (on- and off-farm both locally and outside of the village) also conducted to support livelihoods. Other activities include livestock rearing, skilled labouring, migration to urban areas seasonally or permanently (primarily by men) and small-scale commerce, such as production and sale of crafts (primarily by women).

Based on the conceptual framework developed by Dorward et al. (2009), households in the case study sites were classified at that point in time as either:

1. 'Stepping up' (investing in and expanding current activities, particularly agriculture, in order to improve livelihoods);
2. 'Stepping out' (diversifying away from agriculture to accumulate assets and income to improve livelihoods);
3. 'Hanging in' (attempting to retain existing assets and activities to maintain livelihood levels, often in situations of extreme poverty).

A similar range of classifications for farm-types based on livelihood activities, their output functions and household asset endowment were

found in Burkina Faso by [Thiombiano and Le \(2014\)](#).

Due to the high level of external interventions (from both government and NGOs) that influence farmers' livelihood opportunities, along with a lack of baseline data in the case study sites, it is not possible to clearly determine the direction of causality between livelihood pathway and decisions to adopt/expand WH. However, evidence indicates a strong association between level of dependence on agriculture for livelihood outcomes and WH use, with greater levels of WH adoption (in terms of area and intensity) in households 'Stepping Up' (although there are some important exceptions, as explained below). Heads of household were primarily *Investors* or *Innovators* and their wives were *Passive adopters* or *Receivers*. Many of these farmers continued to expand use of WH over time, particularly zai, to increase the level of income obtained from crop production. Such insights supports research by [Boyd and Turton \(2000\)](#) and by [Tittonell et al. \(2010\)](#) who found farmers most dependent on agriculture for their livelihoods in East Africa were likely to have higher levels of investment in WH.

Extent and intensity of WH use in households 'Stepping Out', in which agriculture was found to contribute only to increased food security (rather than food security and income) was lower than those 'Stepping Up'. Nonetheless, between 78 and 100 percent of households 'Stepping Out' across the case study sites used WH to some extent (see [Fig. 5](#)). Heads of household were generally *Passive adopters* or *Augmenters* and had only decided to adopt or expand WH use with external support and not independently (as done by those 'Stepping Up').

Although the level and variation of dependence on agriculture over time is clearly important in the decision-making process, the SRLF helps to illustrate that the final decision of whether to invest in a particular livelihood pathway, and therefore WH, at a particular time also depends on the level of asset endowments of the household concerned (which in turn is influenced by TSPs) and/or the investment's perceived ability to reduce livelihood vulnerability. In households 'Hanging In', although agriculture made a key contribution to food security and/or income and there was a desire to adopt WH in at least some fields to reduce crop loss, their lack of assets (particularly tools for installation and labour) constrained their ability to do so, even with external assistance.

Within the group of households 'Stepping Up', one third were

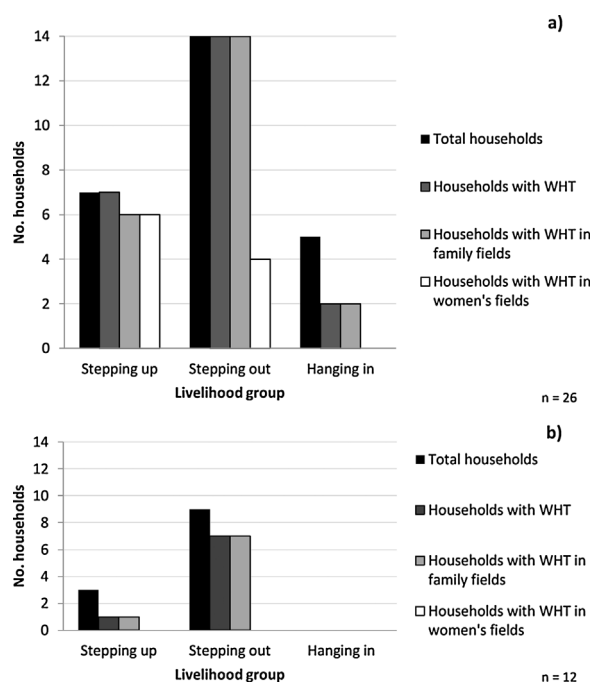


Fig. 5. Characteristics of the use of water harvesting techniques in households across livelihood types in Boukou and Malgretenga (a) and Peni (b).

classified as *Non-users* or *Leavers*, having never adopted WH or had decided to dis-adopt WH after a period of use (either by not reinstalling the following season, or by allowing to fall into disrepair). In these cases, changes to WH use over time were primarily because farmers did not perceive that benefits from WH justified (continued) investment compared to other livelihood options (eg. livestock rearing). This supports the view of [Drechsel et al. \(2005\)](#) who argue that many investigations into factors that influence the adoption and use of WH fail to consider other opportunities for reducing vulnerability and achieving livelihood outcomes available to households through diversification.

3.2.2. Vulnerability context

Rural livelihoods must continually adapt to dynamic, irregular, uncertain conditions imposed by various shocks, trends and seasonal changes ([Ellis, 2000](#)), which can be considered the vulnerability context. Due to their high dependence on agriculture, household vulnerability is closely linked to factors that influence crop production risk. In most cases, interviewees stated that they generally adopted WH (in the first instance) to reduce their vulnerability to erratic rainfall and high runoff. High runoff was considered by farmers to limit crop production due to lack of infiltration and hence water retention in the soil, high soil erosion and hence low fertility, and/or damage to young crops that could not withstand the force of high runoff flows.

Beyond those fields where rainfall runoff was considered to be the main risk to crop growth, farmers did not generally perceive the investment in additional WH to be justified by the potential benefit, despite the fact that dry spells (to which WH is widely promoted as a solution) were identified as the main factor causing crop losses in all case study sites. One of the reasons for this is likely to be because they fail to provide sufficient reduction in crop production risk ([Toulmin and Chambers, 1990](#); [Boyd and Turton, 2000](#)). Malgretenga and Boukou receive around 750 mm annual rainfall and this is close to the limit for WH benefit, as identified by [Bayala et al. \(2012\)](#) from meta-analysis of data from Burkina Faso, Mali, Niger and Senegal, and by [Morris and Barron \(2014\)](#) from in-depth investigation in Burkina Faso. In Peni, decisions were made not to adopt WH as they were considered likely to increase crop loss in some years due to the risk of waterlogging.

Use of the SRLF in this research highlights the way in which WH adoption and use over time both affects and is affected by the vulnerability context within which farmers are situated. It also illustrates how vulnerability context is not just a function of rainfall patterns, but is closely linked to access and control over a range of different livelihood assets, which in turn is influenced by TSPs. In dryland areas, water is unlikely to be the only risk to crop production at any one time ([Rockström et al., 2007](#)) and focusing on water alone does not solve farmers' complex problem of low agricultural productivity ([Oweis and Hachum, 2006](#); [Rockström et al., 2010](#)). Most interviewees reported severe constraints on access to fertilisers and compost, which was related to their endowment with household assets.

3.2.3. Livelihood assets

The identification of which assets (or resources) are necessary to support particular combinations of household activities and how they do so is a key part of any livelihoods analysis ([Scoones, 1998](#); [Carney, 1998](#)). The SRLF used in this research allowed for the influence of the five types of assets (natural, financial, human, physical and social) on WH adoption and expansion to be mapped. As shown in [Fig. 6](#), natural capital (primarily land and water), physical capital (primarily agricultural inputs and technologies), financial capital (primarily wealth and credit), human capital (primarily labour and knowledge), and social capital (primarily institutional and community support) all influenced WH adoption.

Discussions in community feedback meetings emphasised the influence of access to the range of agricultural assets (including traction animals, manure/compost and improved seeds) on farmers' decision making on adoption of WH. Alleviating drought risk through WH often

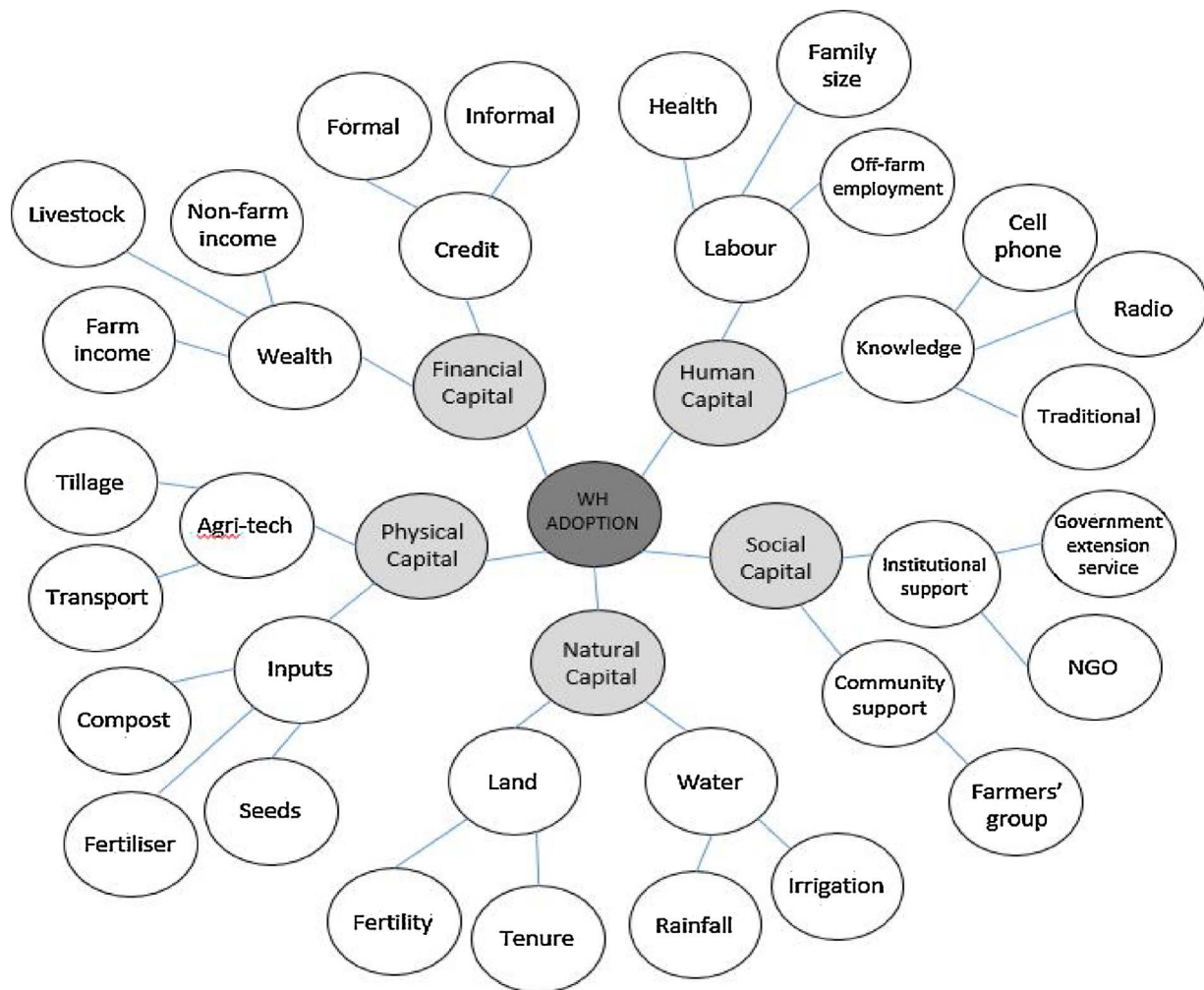


Fig. 6. Mapping natural, financial, human, physical and social capitals and WH adoption.

does not provide sufficient benefits to encourage farmers to adopt.

“We can have water harvesting but if we do not have compost, fertiliser and good seeds, it is nothing”.

[Household head in Boukou]

The availability of assets (particularly compost) was found to limit the number of households in *Investor* and *Innovator* categories. This provides further evidence that an adequate supply of good quality compost and/or fertiliser is crucial to the effectiveness of WH (Zougmore et al., 2004; Molden et al., 2007; Rockström et al., 2007). Yet, perhaps most importantly, it challenges the belief (Rockström et al., 2007) that WH provides the entry point for unleashing the full potential of rainfed agriculture and provides some explanation as to why adoption and expansion of WH across Burkina Faso has been low outside of external interventions that substantially reduce the cost of installation to farmers (Morris and Barron, 2014).

Use of the SRLF to examine livelihoods over time, demonstrates how change in levels of access to assets can alter the use of WH over time. For example, one household stopped using zaï from one year to the next, and hence moved from *Innovators/Investors* to *Augmenters*, as money was not available to buy fertiliser. In another household, the same change in WH type occurred as a family member fell ill causing a lack of labour to dig zaï that year. With more permanent WH structures (contour bunds and stone lines), changes in asset access from year to year influenced the degree of maintenance or expansion. Older farmers, in particular, whose children gradually moved away from the village, were eventually unable to maintain them due to a lack of labour and

preferred to invest in other livelihood activities instead. In such circumstances, stone lines and earth bunds fell into dis-repair and, after some time, households became classified as *Dis-adopters*.

Use of the SRLF also highlighted the under-considered role (Drechsel et al., 2005) that farmers' decisions concerning trade-offs between different livelihood activities can have on WH adoption. It was evident that asset-related constraints have a greater emphasis on the decisions to adopt and expand WH in households 'Hanging In' and 'Stepping Out' compared to those 'Stepping Up'. For households 'Hanging In' this is primarily due to a lack of assets for installation, whereas for those 'Stepping Out' this is more related to their need to invest adequate resources, particularly labour, in the other activities outside of crop production that contribute towards livelihoods. These trade-off decisions were seen to be contingent on the influence that transforming structures (institutions) and processes (TSPs) had on the access of different households to key assets.

3.2.4. Transforming structures and processes

The influence of TSPs on the ability of households to achieve sustainable livelihoods is a central part of the SRLF (Ashley and Carney, 1999; Scoones, 2009). The framework acknowledges that TSPs influence a range of components within the framework: access to and effective value of assets, options for livelihood activities that are possible and attractive, convertibility of assets into another type of asset, and finally, the vulnerability level of individuals and households (Carney, 1998).

In keeping with previous research (Sidibe, 2005; Morris and Barron,

2014), this study found that WH adoption and use in the case study sites could be principally attributed to large-scale external interventions that removed construction-related constraints, including lack of tools and labour. Even wealthier farmers commented that interventions provided valuable assistance with transportation for stones to farmers' fields, which was beyond the capacity of typical carts and traction animals owned within the communities. For *Augmenters*, external interventions were a key factor in their expansion of WH use, with a series of projects providing the opportunity to extend construction across several of their fields. In contrast with experiences reported by Kaboré and Reij (2004), data from this research indicated that external interventions provided limited opportunities for WH adoption for the poorest households. Evidence showed that interventions failed to allow these households to overcome the multiple barriers they experience to WH adoption compared to their wealthier counterparts.

Links between local level institutions and access to assets found in this research match observations made in Burkina Faso by Mazzucato et al. (2001) in their research on WH adoption. For example, informal networks between households provided the opportunity to gain temporary access to labour, ploughs and carts, whereas more formal farming organisations, government extension services, and local markets provided farmers with access to the range of complementary agricultural assets, such as knowledge, improved seeds, compost, fertiliser and land, all of which have a positive effect on WH adoption.

Between and within households, social norms shaped by the culture in the case study sites determined not only asset access and control, but also the broad type of income generating activities men and women engaged in. Individuals and households, therefore, often lack choice or conscious decision in the activities they engage in and the functions they play (de Haan and Zoomers, 2005). As a result of these social norms, women were more likely to invest in small-businesses or livestock production than in agriculture which limited the potential increase in crop production that could be obtained through the adoption of WH and hence motivation to adopt.

3.3. Methodological limitations

In order to gain insights into attitudes to WH adoption, this research uses qualitative methodology based on intensive household level enquiry. The challenge then is to trade-off the depth of enquiry against the sample size needed to establish representativeness. The methodology used in this research follows (Eisenhardt, 1989) framework for building theory from case studies, which draws heavily on case study research design, grounded theory building (Glaser and Strauss, 1967) and qualitative analysis methods. This methodology was selected for the freshness of perspective it provides to an already researched topic and its inductive approach that allowed for an in-depth investigation of WH adoption and use within a real life context (Eisenhardt, 1989; Yin, 2009). As in any grounded approach, the aim of reaching theoretical saturation – the point at which incremental learning for each case added and iteration between theory and data is minimal – drove the data collection and analysis process (Glaser and Strauss, 1967). Iterations between data collection and analysis and theory building continued until the level of change in the themes and theory generated was considered to become as small as could be expected for a study of its size. Comparison of the insights generated in this research with both conflicting and similar literature also played a key role increasing the validity and generalisability of findings (Eisenhardt, 1989: 545).

4. Conclusions

In this paper we have examined adoption of WH as a strategy for small-scale farmers in SSA to adapt to current climate variability and future potential climatic changes in the region. This paper provides deeper insight into the varied and dynamic nature of WH adoption in order to better understand the factors that drive adoption and use at

household level, so that uptake can be increased and benefits widened, both in BF and SSA more broadly. A typology comprising nine different categories outlining the differences in levels of knowledge, extent/intensity of WH use, and the way in which WH was adopted (and in some cases expanded) between farmers was developed. Longitudinal data collected regarding changes to WH adoption and use in households over time highlights that farmers may move between categories as decisions are made to adopt, expand, modify, dis-adopt or re-adopt in response to changing circumstances at household level. For example, one household moved from the *Innovators/Investors* category to *Augmenters* category from one year to the next as money was not available to buy fertiliser. Similarly, as children grew up and gradually moved away from the village, older farmers were unable to maintain WH technologies due to a lack of labour and eventually fell into the *Dis-adopters* category; these farmers preferred to invest in other less labour-intensive livelihood activities, such as livestock rearing, instead of WH. This research provides further support to the growing number of studies that highlight the lack of a universal factor that influences the decision of an individual in relation to WH and that uptake and adoption is instead closely related to a range of factors linked to the varying circumstances at individual and household level (Knowler and Bradshaw, 2007; Sietz and Van Dijk, 2015). Experiences of farmers in the case study sites also fit with broader research on climate change adaptation that illustrates the decision to innovate, or adapt, such as by adopting WH, is primarily determined by a combination of perceptions of knowledge, risk, goals and experience (Grothmann and Patt, 2005; Adger et al., 2009). As observed in 'bright spots' across SSA (Noble et al., 2008), the final decision to adopt, expand or dis-adopt WH (or not) result from 'a synchronized interplay' of various influential factors related not just to agriculture, but livelihoods as a whole. This research demonstrates that, in accordance with wider literature on technological change (Rip and Kemp, 2006), WH technologies are not just tools that are adopted and used, but are shaped by farmers and the context within which they are placed.

The SRLF can facilitate improved understanding of the entire livelihoods system (or 'big picture') within which WH technologies sit, and how and why reasons for adoption and/or expansion of WH by farmers vary. The SRL approach allows for the examination of multi-layered interactions between WH and the various different livelihood components of both households and individuals (Adato and Meinzen-Dick, 2002). It has been possible to shed light on how WH is simultaneously affected by and affects the different livelihood components within the framework (vulnerability context, assets, livelihood pathway and outcomes), and helps to identify key relationships and feedbacks that need to be examined in more detail. Particular consideration of the influence of TSPs has helped to avoid generic observations relating to farmers as a whole and instead emphasised ways in which relationships between WH and livelihoods may not be the same for different types of household and individuals (Levine, 2014). The identification of these relationships has provided a deeper appreciation of how and why TSPs play a key role in shaping how WH is perceived, adopted and expanded, as they do in any innovation or technology related to climate change adaptation (Adams et al., 1998; Adger et al., 2009).

The potential of WH to increase crop production and improve livelihoods across SSA will vary as a result of different socio-economic, institutional and agro-ecological environments. For example, there were clear differences in how crops and other assets are used to meet livelihood needs and aims between and within households across the three case study villages, which is highly influenced by livelihood pathway and level of asset endowment. As suggested by Perret and Stevens (2006), Knowler and Bradshaw (2007), and Vohland and Barry (2009), this research provides a clear indication of why more focus is needed on exploring uptake of WH at the local level to better understand the degree to which WH uptake may be increased and livelihoods improved. The investigation of WH use in households of differing livelihood pathways conducted as part of this research ('Stepping Up',

‘Stepping Out’ and ‘Hanging In’) is a first step to improving the understanding of the complex conditions that influence WH adoption in different types of household that Seitz and Van Dijk (2015) stated was urgently needed. This analysis has helped to identify entry points for WH-related interventions in SSA aimed at improving food security and livelihoods in different households, which is vital to ensuring the development of more effective interventions and policies.

The drylands of SSA are known to be highly dynamic systems, with a complex context of risk and vulnerability (Sietz et al., 2017). Findings from this study are consistent with the conclusions from ‘bright spots’ research (Pretty et al., 2006; Noble et al., 2008; Bossio et al., 2008) on the absence of spontaneous adoption of agricultural innovations, such as WH, and the important role of external priming agents. This evidence suggests that, contrary to popular belief (Rockström et al., 2007; Biazin et al., 2012), WH innovations cannot be relied upon to unlock the potential of rainfed agriculture in SSA. Approximately 50% of farmers in the study sample had either not actively adopted, were not using, or had no knowledge of WH (Table 2). Although WH has been promoted and implemented widely in BF since the 1960s and evidence from experimental plots and from farmers’ fields appears to show that a range of SWC practices can deliver increased productivity across the drylands of West Africa (Bayala et al., 2012), this study provides a deeper understanding of why there has been limited diffusion of the innovation beyond areas of external intervention in both Burkina Faso (Morris and Barron, 2014) and SSA more widely (AfDB, 2007; Molden et al., 2007). These lessons from WH experience in Burkina Faso have wider implications for the promotion of climate adaptation innovation for small-scale farmers in SSA.

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